1 BIO-Plex Pinch Analysis: Data Collection for BIO-Plex System Level Energy Integration
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Summary

1. The status of the energy integration work for the ALS power reduction grant is given.

2. Background information on the research goals and approach is presented.

3. The initial data collection step is discussed.

4. The next steps for the research are discussed.

Introduction

The systems modeling and analysis group at Ames Research Center is currently working on the first year tasks for the grant entitled "Advanced Life Support Power Reduction." The Advanced Life Support Power Reduction research involves developing approaches for reducing system power and energy usage in Advanced Life Support (ALS) regenerative systems suitable for exploring the Moon and Mars. The effects of system configuration and processor scheduling are being investigated, along with system energy integration and energy reuse techniques and advanced control methods for efficient distribution of power and thermal resources. Here we discuss progress to date on applying system energy integration and energy reuse techniques to the life support problem.

Approach

One of the main objectives of the power reduction research is to develop system designs that are more efficiently integrated from an energy standpoint, so that the equivalent system mass of future life support systems can be reduced. Hot and cold streams within the system can be matched and their energy exchanged in order to lower the external cooling and heating requirements. Some subsystem designers have taken advantage of energy integration within their subsystem design in order to minimize power usage. However, due to limitations on the number of available hot and cold streams within a given subsystem, only partial energy reuse is generally achievable. A system approach to energy integration will inevitably yield better results than the more common subsystem-by-subsystem power optimization approach. When the entire system is treated, there is much more flexibility in the design approach, and the potential for energy reuse is substantially greater.

In *A User Guide on Process Integration for the Efficient Use of Energy* by B. Linnhoff, energy integration techniques are discussed. Using the simple, practical method outlined in Linnhoff's book, referred to here as the “Pinch Technique”, system design options can be identified that lower the overall system energy usage. In the Pinch Technique, first, process streams and their thermal attributes (heat capacity flowrate, supply temperature and target temperature) are identified. The heat duty that is required to bring each stream from its supply temperature to its target temperature is calculated. Next, composite curves are constructed, first for the streams that require cooling (hot streams), then for the streams that require heating (cold streams). The hot composite curve contains the aggregate energy content information for all of the hot streams, and the cold composite curve contains all of the aggregate energy content information for all of the cold streams. The hot and cold composite streams are plotted together in a heat content graph, and the minimum heating and cooling requirements for the system are identified. An energy cascade (a net enthalpy balance on the system) is performed to identify the locations where external heating and cooling must be supplied. Once the energy cascade has been completed, an optimal system heat exchange design can be developed by matching hot and cold streams such that heat exchanger loads are maximized, so that the total number of exchangers can be minimized. For a more detailed explanation of the Pinch Technique, please refer to the attached NRA proposal "Advanced Life Support Power Reduction".

Year One Goals and Tasks

The goal for year one of the energy integration work is to develop thermally-integrated system designs using the BIO-Plex as a baseline system. Specific tasks for the first year include:

1) Identify candidate technologies and designs for the BIO-Plex.

2) Identify potential hot and cold streams for candidate technologies.

3) Develop energy content data for each hot and cold stream using mass and energy flow models as needed to produce temperature, flow and composition data.

4) For various candidate designs, identify and quantify potential savings for power, heating and cooling, and make estimates on the increase in emplaced mass needed for energy exchange equipment.

5) Make recommendations on system designs that incorporate energy reuse.

6) Prepare a report and/or research paper to document the results listed above.

Current Status

To date, progress has been made on tasks 1, 2 and 3 above. The attached EXCEL spreadsheet contains information compiled from various sources on thermal flow characteristics of candidate BIO-Plex technologies. Different subsystems (atmosphere revitalization, water recovery, solids processing, biomass production, food processing and habitat) are separated by spreadsheet, as listed on the tab at the bottom of the spreadsheet frame. Within each subsystem, technologies are categorized according to function, as denoted by the gray tags to the leftmost edge of each sheet. Technologies within a function tag are further categorized as used in the LMLSTP Phase III Test Bed, planned for the ISS, candidate BIO-Plex technology, or 'other technology'. A particular technology may be listed in a sheet more than once. For instance, Four-Bed Molecular Sieve is listed on the atmosphere revitalization sheet under the LMLSTP Phase III Test Bed as well as the ISS, with data representative of each location. The spreadsheet does not include data for every piece of electrical equipment planned for the BIO-Plex. The spreadsheet includes data only for equipment in which heating and/or cooling of flowstreams may be required.

Data is displayed under several column headings (stream flowrate, stream composition, supply temperature, target temperature, etc.), and "notes" on a particular piece of information are occasionally included (denoted by a red triangle in the upper right corner of a cell). Notes can be viewed by holding the mouse directly over the cell of interest. The source of the information is listed under the "source" column, or in a cell note, when referring to one piece of information. The sources are described more completely under 'References' below. The columns of data that are included in the spreadsheet will allow for future calculation each stream's heat duty.

The name of the process and the stream of interest are in the first two columns. Most technologies will have at least one inlet stream and one outlet stream, and some technologies have more than one inlet or outlet stream. Separate rows of data are listed for every stream of a process. Stream composition will be used to calculate stream heat capacities, which will be discussed in a later memo. The heat capacity of a stream is one of the properties required for calculating the heat duty.

Average stream flowrate is taken from the source document for the particular conditions in which the technology was utilized. The mode column delineates the flow as continuous, batch or semibatch. The column for the typical duration of use lists the amount of time for which a process is normally run in that mode. Streams in a system must be compatible in terms of mode and duration in order to be mixed for energy exchange.

The number of crew supported by the process at the given flowrate is mission and design dependent. For example, in the LMLSTP Phase III Test Bed, CO_2 reduction was performed with a Sabatier unit at a flowrate of approximately 0.2kg CO_2 per day. This processing rate is related to the amount of food that was grown, crew activity, incineration rates and other system attributes. In a system with different attributes, the processing rate for four crew members would be different. Because of this, all future scaling of equipment power requirements must be done with respect to flowrate, rather than number of crew supported by the processor.

For an inlet stream, the supply temperature is the temperature of a stream immediately preceding the process of interest , and the target temperature is the desired temperature of the stream during processing. For an outlet stream, the supply temperature is the temperature of the stream during processing, and the target temperature is the desired temperature of the stream immediately following processing. The heat source or heat sink used for bringing a stream to the target temperature denotes the potential amount and type of energy that could be saved if this stream were mixed with another hot or cold stream to reach the target temperature. Energy can be saved by reducing the load on the HVAC system, reducing electrical heating requirements, or reducing cooling water requirements.

At the top of the biomass production spreadsheet, three possibilities are given for lamp intensity, depending on which of three ballast levels are utilized. Also at the top of the sheet, lamp and ballast cooling requirements are listed per lamp to enable calculation of heat loads for various lamp illumination combinations in a light box. In the bottom portion of the biomass production spreadsheet, calculations are shown for maximum cooling requirements for each crop tray, given full lamp intensity (400W) and all lamps on.

Where Do We Go Next?

In addition to continual updating of the attached spreadsheets, future work will focus on tasks 1, 3 and 4 above. Heat capacities for each stream in the spreadsheet will be calculated, and candidate operational designs and schedules for the BIO-Plex will be developed. This will enable calculation of the heat duty associated with each hot and cold stream, which is a function of the stream flowrate, heat capacity and temperature differential. The heat duty, supply temperature and target temperature will enable determination, via the Pinch Technique, of which streams may be integrated and how much power may be conserved. Potential savings for power, heating and cooling, as well as estimates on the increase in emplaced mass needed for energy exchange equipment will be quantified.

Accurate representation of technology flow streams is required for legitimate suggestions for power reduction techniques. Therefore, feedback from researchers in the ALS community is very desirable. Any comments, corrections or questions are encouraged and should be directed to Julie Levri at jlevri@mail.arc.nasa.gov , or (650) 604-1955.

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